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Opportunities to Increase Tree Planting in Shelterbelts and the Potential Impacts on Carbon Storage and Conservation

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Chapter 9

Opportunities To Increase Tree Planting in Shelterbelts and the Potential Impacts on Carbon Storage and Conservation

By James R. Brandle, Tom D. Wardle, and Gerald F. Bratton

Introduction

Forestry offers many opportunities to sequester carbon dioxide from the atmosphere and mitigate the impacts of global warming. One such opportunity is the planting of shelterbelts—wind barriers of one or more rows of trees and/or shrubs. While many may consider shelterbelts to be of minor importance in terms of land area planted to trees, it is important to remember that the area protected by a shelterbelt may, depending on its height, be from 10 to 20 times the area actually planted to trees. The indirect benefits gained on these protected areas would have a significant impact on the total carbon dioxide balance.

Shelterbelts come in many sizes, shapes, and configurations. They are used to protect ranch and farm homes, crop fields, livestock, and roads. They are planted to enhance wildlife habitat, to provide privacy, and to improve the aesthetic qualities of the landscape. Ultimately, however, the contributions of shelterbelt plantings to reducing the use of fossil fuels and capturing carbon may exceed these traditional values for shelterbelts.

Shelterbelt Plantings Today

The latest inventory of shelterbelts, completed in 1987, indicates that there are just over half a million farmstead and livestock shelterbelts (table 9.1) covering about 766,000 acres and protecting about 23 percent of all farms (U.S. Department of Agriculture, Soil Conservation Service 1990 unpubl.). Nearly 90 percent of these shelterbelts are located in the North Central region, where 55 percent of farms are already protected. This area includes the Great Plains, a prairie with little natural tree cover and persistent winds. Most of the remaining shelterbelts are in the Rocky Mountain region.

The same survey indicates that there are almost 350,000 field shelterbelts that extend for a total distance of about 115,781 miles (table 9.2). These shelterbelts protect 8.4 million acres of cropland. While this acreage is substantial, it represents only 2 percent of the total crop acres in the United States. Most of the field shelterbelts (295,748) and most of the acres protected (7 million) are in the North Central region. Even with this concentration, however, only 3 percent of the total crop acres in this region are protected. In most of the regions, less than 1 percent of the crop acres are protected by shelterbelts.

Estimates for the other types of shelterbelts or windbreaks are essentially unavailable. Several States have inventoried "living snow fences" (Colorado, 32 miles; Nebraska, 66 miles; South Dakota, 12 miles; Wyoming, 4 miles; personal communications, State Forester offices), but the extent of other types of plantings is largely unknown.

snow stored increases with the height of the snow fence. Slatted snow fence stores only 5.4 tons of snow per linear foot.

Wyoming has devised larger snow-control structures that are permanently located along various roads and have an average service life of 35 years. These structures store 67 tons of snow per linear foot and are considerably cheaper—$20 per unit of snow storage per mile per year.

Both of these artificial structures are expensive when compared to a three-row living snow fence, which stores 68 tons of snow per foot, costs only $3 per unit of snow storage per mile per year, and has a service life of 75 years. These living snow fences also provide valuable wildlife habitat in areas with little other winter protection.

Although the number of miles of artificial snow fence erected each year is unknown, potential savings from living snow fence establishment can be determined on a per-mile basis. A typical living snow fence will require two to three rows of conifers at a within-row spacing of 8 to 10 ft. Using these guidelines, approximately 1 million to 2 million trees on 3,000 to 5,000 acres will be required per 1,000 miles of living snow fence.

Areas in the northern half of the United States, especially those in the Plains States and in mountainous areas, would benefit most from reduced snow drifting. Table 9.5 summarizes the number of miles of highways in rural areas in those States most likely to benefit from a living-snow-fence program. Protecting as little as 1 percent of the rural roads in these States would require 6,370 miles of living snow fences, or approximately 6.4 million to 12.7 million trees on 19,000 to 32,000 acres. Because only 113 miles of living snow fence are in place, there are very large opportunities for snow protection (and consequent carbon sequestration) in making new plantings of living snow fences.

Livestock Shelterbelts

Shelterbelts to protect livestock are designed to provide protection during the winter. Such shelterbelts are usually three to five rows wide and consist of a row of shrubs, one or two rows of conifers, and one or two rows of tall hardwoods. A feedlot designed to hold 500 head of feeder cattle should cover about 3 acres (Hintz 1983). A three-row shelterbelt to protect such a feedlot would occupy just under 1 acre and require a combination of 294 trees and shrubs. A five-row belt would cover 1.5 acres and utilize 424 trees/shrubs.

Table 9.6 gives the number of cattle on feed in this country as of January 1, 1988. Of the 11.5 million head, over half are located in States where winter conditions would justify wind and/or snow protection. To protect just 10 percent of the cattle in these States would require 175 miles of three- to five-row shelterbelts and would entail planting a total of between 330,000 and 490,000 trees and shrubs on 1,000 and 1,700 acres.

Over two-thirds of the dairy cattle in the United States are located in States where winter conditions would justify wind and/or snow protection. Because dairy cattle require more space per animal than beef cattle, the hypothetical feedlot described above would hold only 312 head (Hintz 1983). Thus, to protect 10 percent of dairy cattle would require 343 miles of windbreaks, or a total of between 670,000 and 977,000 trees and shrubs on 2,500 to 4,200 acres.

Other Shelterbelt Plantings

Additional plantings for wildlife habitat would add significantly to the above totals. Tree requirements for these shelterbelt plantings depend on the type and size of the planting. Wildlife plantings are commonly 3 to 5 acres with five to eight rows or more—two or three rows of conifers, one or two rows of tall hardwoods, and two or three rows of shrubs. Shrub spacing is normally 5 ft within the row; conifers, 10 ft; and hardwoods, 16 ft. A planting of 3.2 acres would be 140 ft wide and 1,000 ft long and require 250 to 400 trees per acre. The need for wildlife plantings in most of the Great Plains is substantial, and the opportunities to encourage these plantings are many.

Plantings in urban areas are discussed in other chapters. This chapter considers only those plantings that are needed to protect the many acreage developments occurring at the interface between urban and agriculture areas. Data for five cities in the Great Plains are outlined in table 9.7. The building site on any of these acreages can be adequately protected by a four-row shelterbelt (one row of shrubs, two rows of conifers, and one row of tall hardwoods) with a total length of 208 ft, requiring 157 trees/shrubs for each site.

While it is impossible to determine a total national need for this type of planting from the data available, an estimated 15.7 million trees on 28,650 acres would be required for each 100,000 building sites of this nature. The number of these types of plantings is rapidly increasing as populations in midsize cities grow. Again, the opportunities to encourage these types of plantings are abundant.

Summary of Shelterbelt Planting Needs

Table 9.8 summarizes the potential opportunities for minimum shelterbelt plantings in the United States, excluding wildlife and homesite plantings for which no estimates are available. In all, meeting minimum needs would involve planting a total of 1.3 billion trees and shrubs in 1.9 million miles of rows covering some 4.9 million acres of land. Most of these trees and shrubs would be planted in field shelterbelts—920 million for control of wind erosion and 321 million for crop protection. Another 555 million trees/shrubs would be required to meet the minimum needs for farmstead shelterbelts. The remaining trees and shrubs would be planted to protect livestock and to form living snow fences.

Planting 1.3 billion trees represents a substantial effort in providing wind protection but in reality it is a minimum shelterbelt planting program. Except in the case of wind erosion control, the estimates of planting needs are conservative goals. In particular, the opportunities for field shelterbelts to enhance crop production are far more extensive than indicated. A national goal to protect 40 percent of the cropland in the United States would require the planting of an additional 1 billion trees on 3.5 million acres.

Long-Term Carbon Dioxide Storage in Shelterbelt Vegetation

The preceding section quantified and described minimum planting opportunities for shelterbelts. This section addresses the biomass shelterbelt plantings can produce and the amount of carbon dioxide they can store.

Shelterbelt plantings are unique. On a per-acre basis, stocking levels are low, generally in the range of 130 to 270 trees per acre regardless of tree age or size. Stocking levels for shrubs are 400 to 500 plants per acre, again very low relative to the potential productivity of the site. As a result, the figures used are derived from volume and weight estimates on several low-productivity sites. They represent best estimates of biomass and have not been empirically tested.

The U.S. Department of Agriculture's Forest Service conducts and publishes forest inventories. From these data, average tree volumes for species commonly used in shelterbelts were compiled. Tree heights at 20 years as predicted by the Soil Conservation Service's technical guidelines (table 9.9) would correspond with the 5- to 6.9-inch diameter class in the forest inventories. Using the number of growing-stock by diameter class, we calculated the average aboveground tree volume for various species (table 9.10). Growing-stock volume is approximately 65 percent of the total wood volume of the tree (Wenger 1984) with the remaining 35 percent split between the crown and the roots. Tree volumes were adjusted to reflect total tree volume of solid wood. Leaf and needle volumes were not considered because they are cycled on a short-term basis.

Shrub biomass was much more difficult to assess. Nord and Countryman (1971) estimated fuel loads for brush stands in California at between 2 to 15 tons dry

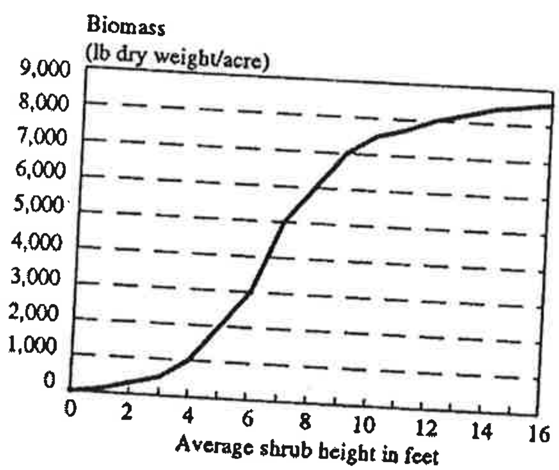

Figure 9.1—Estimated biomass of windbreak shrubs at a density of 400–500 plants per acre.

weight/acre (light brush, stems less than 3 inches in diameter, height less than 5 ft) and 30 to 50 tons dry weight/acre (heavy chaparral, stems up to 6 inches in diameter, height 8 to 20 ft). Smith (1986) described the shrub component found under 13 different forest types in the northern Lake States. Average shrub biomass ranged from 3,036 to 8,659 lb green weight/acre. Under an elm–ash–maple forest type in northern Minnesota, speckled alder biomass exceeded 15,000 lb green weight/acre. A pure speckled alder stand harvested to determine the fuelwood potential of the species produced 25.3 tons green weight/acre of stems and branches with a stand density of 5,000 plants/acre (Mattson and Winsauer 1985).

Obviously, shelterbelts cannot be directly compared to these situations, but these figures are indicative of the range of biomass production by shrub communities. Using these ranges of biomass productivity and shrub height from the Soil Conservation Service's technical guidelines (table 9.9)—and assuming that shelterbelt shrub plantings are approximately equivalent to a 30-percent stocking level—biomass estimates were calculated for shrubs by height (see fig. 9.1).

A summary of biomass factors used to estimate the carbon storage in a typical conifer, hardwood, or shrub is presented in table 9.11. While hardwoods tend to have greater biomass per tree than conifers (116 lb *v.* 98 lb), a conifer shelterbelt will have a greater total biomass than a hardwood shelterbelt because of spacing and size (26 tons *v.* 19 tons). Height estimates are based on the 20-year planting age used by the Soil Conservation Service for shelterbelt design. These heights represent only 30 to 60 percent of the tree height at maturity. Because total volume and biomass are based on this 20-year height, they, too, represent only a portion of the total biomass at plant maturity.

Carbon dioxide storage in woody vegetation, including shelterbelts, is correlated with biomass on a weight-per-unit-area basis. Richard Birdsey (personal communication 1990) has defined the basic relationship between tree volume and carbon dioxide equivalent. Using the all-timber forest type for each region and the lowest productivity class for commercial forestland (20 to 50 cubic feet of wood per year) as a basis, 1 cubic foot of wood contains 17 pounds of carbon, or an amount equivalent to 62 pounds of carbon dioxide. Birdsey's chapter in this book further explores the relationship between biomass and carbon storage.

Species, growth rates, and spacing between rows of plants and between plants within the row all influence the quantity of carbon dioxide sequestered within a shelterbelt. It is useful, however, to define the amount of carbon dioxide sequestered in a typical shelterbelt of conifers, hardwoods, or shrubs. Table 9.12 illustrates the amount of carbon dioxide equivalent in various kinds of shelterbelts. For example, a 20-year-old, single-row conifer shelterbelt 1 mile long will contain about 1,900 cubic feet of wood and contain carbon equivalent to 54 metric tons of carbon dioxide. On the average, a single-row shelterbelt of assorted species can be expected to store almost 10 metric tons of carbon.

Summary of Direct Benefits

A program designed to meet the minimum shelterbelt planting needs identified would result in the establishment of 1.9 million miles of shelterbelts (table 9.13). These shelterbelts would contain 1.3 billion trees on almost 5 million acres. They would sequester 22.2 million metric tons of carbon, nearly all stored in field shelterbelts designed to protect crops and reduce wind erosion.

If a more aggressive program of establishing field shelterbelts were undertaken and a goal of protecting 40 percent of U.S. cropland were to be achieved, an additional 1 billion trees would have to be established. These additional trees would occupy 3.4 million acres and would contain 21.5 million metric tons of carbon with a carbon dioxide equivalent of 78.7 million metric tons. The total direct benefit of a more aggressive program to plant 2.3 billion trees could result in the storage of 43.9 million metric tons of carbon with carbon dioxide equivalent of 160.2 million metric tons.

Indirect Benefits of Shelterbelt Plantings

The impacts of increased shelterbelt planting on the amount of carbon dioxide sequestered would be substantial. The indirect benefits of shelterbelts in terms of reduced carbon dioxide emission from savings in the use of fossil fuels are also important.

By providing protection to farmstead and homes, shelterbelts cut energy consumption for heating from 10 to 25 percent (DeWalle and Heisler 1988). Shelterbelt-facilitated protection of livestock increases feed efficiency 13 to 50 percent in winter and the production of milk by dairy cattle by 9 to 76 percent (Hintz 1983). Crop yields are increased 6 to 50 percent by field shelterbelts (Kort 1988). Living snow fences reduce accidents associated with winter weather and reduce roadclearing costs as much as 30 percent (Tabler and Furnish 1982).

The following sections of this chapter describe the fuel savings accumulated as a result of wind protection and the reduction in carbon dioxide emissions resulting from this reduced fuel use.

Crop Protection

The beneficial effects of wind protection on crop production are well established (Kort 1988, Baldwin 1988, Sturrock 1984, Grace 1977), and the impacts of shelterbelts on crop yields and economics are being recognized (Brandle et al. 1984 and 1988). In general, land that is protected from wind is more productive per unit area than exposed land, and total crop output goes up on protected acreage. On shelterbelt-protected farms, fewer acres need to be planted to realize the same—or even increased—outputs. Attendant savings can be realized from reductions in tractor and equipment hours and the use of less fuel, fertilizers, and pesticides per unit of production.

In 1988, producers in the United States harvested 58.2 million acres of corn, 39.8 million acres of winter wheat, and 57.4 million acres of soybeans. Using these data, the potential savings generated by protecting 10 percent of these 155.4 millon crop acres can be determined.

A shelterbelt design where trees and shrubs occupy 6 percent of the land area to be protected will totally protect the crop acres by year 20 (Brandle et al. 1988). Such a design assumes a tree height of 25 ft and a zone of protection of 15H after 20 years. Tree height, shelterbelt width, and acreage increase linearly during the first 20 years. Benefits of protection are assumed to begin in year 7, to increase linearly and reach a maximum at year 20, and to continue at the level until year 50. Yield increases in years 7 through 50 in the sheltered areas more than compensate for the crop production lost on those acres planted to trees (Baldwin 1988, Brandle et al. 1988, Kort 1988).

Fuel savings for each crop using Nebraska crop budgets developed by Jose et al. (1989) were calculated. These budgets illustrate the variable fuel use associated with different cropping systems in Nebraska. While actual fuel use varies by location and cropping system, the Jose team's data are useful in determining the potential savings that could be realized by reducing crop acres. Fuel savings from reduced crop acres (table 9.14) begin in year 1 but are partially offset by tree establishment practices, and no fuel savings are assumed during the first 5 years even though some savings may occur.

In the case of corn, if 10 percent of the acres (5.8 million acres) are to be protected, 349,000 acres of shelterbelts will be required. These acres would be removed from production, and, over the life of the shelterbelt, 65 million gallons of fuel would be saved. Based on carbon dioxide emissions of 10.2 kilograms per gallon of fuel burned, the conservation of 65.2 millon gallons of fuel would reduce carbon dioxide emissions by 655,000 metric tons. For soybeans and winter wheat, when 10 percent of the crop acres are protected by shelterbelts, fuel savings of 49.3 million and 25.6 million gallons, respectively, would accrue.

Total estimated fuel savings for all three crops of the 50-year life expectancy of typical shelterbelts is 140.1 million gallons. Carbon dioxide emissions go down by a total of 1.4 million metric tons. This figure approximately equals the amount of carbon dioxide sequestered in 20,000 acres of commercial forestland producing 20 to 50 cubic feet of wood per acre per year.

Shelterbelt plantings and concomitant reduction in farmed acreage lead inevitably to reduction in the use of fertilizers. Corn, in particular, has a high fertilizer requirement. During the period 1971–83, 95 percent of the corn acres in Nebraska received nitrogen fertilizer at an average annual rate of 140 lb/acre (Aschwege and Dobbs 1984). Assuming that a rate of 140 lb of nitrogen/acre is an average nitrogen fertilizer rate for acres in all areas, then the removal of 328,045 acres from corn production for shelterbelt planting would result in a savings of 22,963 tons of nitrogen fertilizer per year.

According to the Fertilizer Institute (Wiese 1974), 36,325 cubic feet of natural gas are required for the production of each ton of ammonia, the basic form of nitrogen from which almost all other nitrogen fertilizers are made. Thus, by conserving 22,963 tons of fertilizer, a potential annual savings of 834.1 million cubic feet of natural gas could be realized. Over the 50-year life of the shelterbelts, more than 40 billion cubic feet of natural gas could be conserved. Similar savings of 5.4 billion cubic feet for winter wheat production and 1.1 billion cubic feet for soybean production could be realized when shelterbelt acres are removed from production.

The literature also suggests (Brandle et al. 1988, Kort 1988) that shelterbelts can increase crop production levels above what would be necessary to compensate for the number of acres withdrawn from crop production. This additional production will reduce the rate at which additional crop acres will need to be added in the future to meet growing food needs. As a result, increases in fuel and fertilizer requirements will be less and carbon dioxide emission levels will rise more slowly with sheltered crop fields than if the fields were unprotected.

Wind Erosion

The effects of wind erosion are often very difficult to observe, and their impact on production can be extremely slow and may appear negligible. Over the long term, however, lost productivity adds up.

Table 9.15 summarizes the potential number of acres of cropland (935,000) needed in the future to replace the productivity that will be lost over the next 100 years due to wind erosion in 13 States if conservation measures are not taken. Replacing this lost productivity will require the conversion of pastureland, rangeland, and/or timberland to crop production. Farming these added acres will require additional inputs of fuel and fertilizer. Since it is unlikely that the damaged lands will be withdrawn from production, farming these acres will require continued inputs of fuel and fertilizer.

Assuming that over the next 100 years these acres can be added to the production stream, farming them would consume a minimum of 128 million gallons of diesel fuel (in a scenario where the most fuel-efficient crop, winter wheat, is planted on all acres). Exhaust emission would give off about 1.3 million metric tons of carbon dioxide. That figure compares to the amount to carbon sequestered by about 18,000 acres of commercial forestland of the type capable of producing 20 to 50 cubic feet of wood per acre per year.

Establishing new shelterbelts to control wind erosion could reduce the need for additional cropland and thus limit the increase in fuel consumption and carbon dioxide emissions predicted for the future.

If additional croplands are added to the production stream, the amount of fertilizer input will increase. Furthermore, as productivity decreases on damaged acres, producers may add additional fertilizer to compensate for lost productivity. In both cases, it is impossible to estimate the total effect on natural gas consumption or carbon dioxide emissions.

The offsite costs associated with soil erosion are extremely difficult to determine. Huszar and Piper (1986) have indicated that such costs are substantial. Of concern here are the energy expenditures for the removal of soil from road ditches, lakes, streets, etc.—a process that requires the use of equipment powered by fossil fuels and emitting carbon dioxide. Unfortunately, no estimates of fuel usage are available. However, if the fuel consumption of heavy equipment necessary to accomplish these tasks is similar to that of farm equipment (averaging 5 gal/h, Jose et al. 1989), carbon dioxide emissions of 51 metric tons per 1,000 hours of equipment operation could be anticipated.

Farmsteads and Rural Homes

The benefits associated with wind protection of homes are well established and have been reviewed by DeWalle and Heisler (1988). The greatest economic benefit is derived from the energy savings accumulating as a result of the reduction in air infiltration rates. Savings vary with climate conditions and home construction, but DeWalle and Heisler's estimates of savings indicate a reduction of 10 to 30 percent in fuel consumption and winter heating costs.

Assume a home with a basic heating requirement of 70,000 British thermal units (BTU) per hour. Using a standard estimating procedure (Strock 1959), it is possible to compare the total annual heating requirement of this hypothetical home located in different climatic regions and the savings that would result from shelterbelt protection (table 9.16). As expected, maximum savings would occur in the more northern areas.

In addition to the fuel conservation value of shelterbelts, significant reductions in the emission of carbon dioxide are recorded. Table 9.16 itemizes these reductions for each of the situations considered in the example.

Total regional and national savings based on planting shelterbelts to protect 146,741 additional homes in the North Central, Rocky Mountain, and Pacific Northwest regions are summarized in table 9.17. Total reduction in carbon dioxide emissions would be 206 millon metric tons over the 50-year lifespan of the shelterbelts. This figure is approximately equivalent to the amount of carbon dioxide sequestered in 2.9 million acres of commercial forestland capable of producing 20 to 50 cubic feet of wood per acre per year.

Living Snow Fences

Tabler and Furnish (1982) reported the benefits of wind protection by snow fences on a 62-mile section of Interstate 80 in Wyoming. Most important was a 70-percent reduction in winter weather-related accidents, reflecting the improved visibility and road-surface conditions in the protected areas. Tabler and Furnish also estimated a 33-percent reduction in expenditures for snow and ice removal for the protected section, saving $563,000 over the period 1976-81. If fuel costs are assumed to be 10 percent of the total spent for snow removal, and fuel costs averaged 77 cents/gal over the 5 years, then the shelterbelt accounted for savings of 73,116 gallons. On a per-mile, per-year basis, this figure translates to 321 gal/mile. This fuel conservation represents a reduction in emissions of 3,278 metric tons of carbon dioxide per 1,000 miles of highway protected by snow fence per year.

Summary of Indirect Benefits

The indirect benefits of wind protection come in the form of increased crop production, reduced wind erosion, and increased efficiency in agricultural production. The reduction in fossil fuel consumption (diesel fuel and natural gas) resulting from a tree-planting program designed to plant 4.6 million acres of field and farmstead shelterbelts could result in a total reduction of over 209 million metric tons of carbon dioxide emissions over the 50-year lifespan of these shelterbelts. Most of this reduction results from farmstead planting, and is approximately equivalent to the amount of carbon dioxide stored in 2.9 million acres of commercial forest land of the type capable of producing 20 to 50 cubic feet of wood per acre per year.

The indirect benefits of shelterbelts are greatest for those planted to protect farmsteads and ranches. A minimum planting program designed for those homes described in table 9.4 would protect approximately 11 percent of the U.S. farmsteads and ranch homes currently unprotected. If a more aggressive planting program were undertaken, resulting in the protection of a total of 23 percent of unprotected homes, indirect savings through reduced carbon dioxide emissions would double to over 400 million metric tons over the 50-year lifespan of such shelterbelts.

Conclusions

Planting shelterbelts is an extremely efficient use of land in efforts to reduce atmospheric carbon dioxide concentrations. Not only is carbon sequestered in the growing trees, but the wind protection provided in the lee of shelterbelts leads to additional savings. Crop production is enhanced, resulting in fuel savings. Wind erosion is reduced, thus decreasing the demand for additional crop acres and the related fuel expenditures. Heating requirements of homes protected from the wind are reduced, resulting in fuel savings.

A minimum windbreak planting program of 4.9 million acres would result in the storage of 22.2 million metric tons of carbon. Indirect benefits in the agricultural sector would reduce diesel fuel consumption by 328 million gallons. Wind protection of homes would reduce home heating needs and conserve over 180 billion cubic feet of natural gas. These reductions in fossil fuel use could reduce carbon dioxide emissions by 291 million metric tons over the 50-year lifespan of the windbreak plantings. Much greater benefits could be achieved with a larger planting program.

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Table 9.1—Number of farms[1] and farmstead shelterbelts in the United States, by region, 1987

Region	Number of farms	Farmstead shelterbelts	
		Number	*Percent of farms protected*
Northeast	335,750	10,302	3.1
North Central	801,500	440,355	54.9
Southeast	256,000	1,188	0.5
South Central	505,000	[2]9,369	1.9
Rocky Mountain	119,900	38,384	32.0
Pacific Northwest	153,000	8,696	5.7
Total	2,171,150	508,294	23.4

Sources: U.S. Department of Agriculture 1989a; U.S. Department of Agriculture, Soil Conservation Service 1990 unpubl.

[1] A farm is an establishment that, as of June 1, sold or would normally have sold at least $1,000 worth of agricultural products during the year. (The number of farms may be larger than the number of farmsteads.)

[2] In the South Central region, all farmstead shelterbelts are located in Oklahoma and Texas. In these two States, 4.1 percent of the 230,000 farms are protected. In the rest of the region, no farms have shelterbelts.

Table 9.2—Total crop acres, number and miles of field shelterbelts, and area protected by them, by region, 1987

Region	Total crop acres	Total shelterbelts	Miles of shelterbelts	Acres protected	Percent protected
Northeast	35,202,400	3,266	448	32,614	0.1
North Central	220,918,200	295,748	96,285	7,009,548	3.2
Southeast	24,179,200	2,812	704	51,251	0.2
South Central	75,219,500	15,516	4,989	363,199	0.5
Rocky Mountains	44,234,500	21,759	11,117	809,318	1.8
Pacific Northwest	22,314,300	8,778	2,238	165,926	0.7
Total	422,068,100	347,879	115,781	8,431,856	2.0

Sources: U.S. Department of Agriculture 1989b; U.S. Department of Agriculture, Soil Conservation Service 1990 unpubl.

Table 9.3—Non-Federal cropland in the United States eroding at rates greater than the tolerance level (T), due to wind erosion

Region	Cropland
	Thousand acres
Northeast	200.0
North Central	30,649.4
Southeast	323.0
South Central	17,918.4
Rocky Mountain	16,259.8
Pacific Northwest	2,100.6
Total	67,451.2

Source: U.S. Department of Agriculture 1989b.

Table 9.4—Opportunities for new farmstead and ranch shelterbelts in the United States, by region

Region	Unprotected farmsteads	Protection goals[1]	Acres of trees
Northeast	325,448	10,000	16,000
North Central	361,145	[2]90,286	144,458
Southeast	254,812	1,000	1,600
South Central	495,631	[3]20,000	32,000
Rocky Mountains	81,516	[2]20,379	32,606
Pacific Northwest	144,304	[2]36,076	57,722
Total	1,662,856	177,741	284,486

[1] Number of new shelterbelts to establish.
[2] 25 percent of unprotected farmsteads.
[3] *Primarily in Oklahoma* and Texas.

Table 9.5—Public road and street mileage in rural areas, by functional system, for those States most likely to benefit from a living snow fence program

State	Inter-state	Other principal arterial	Minor arterial	Major collector	Minor collector	Local	Total
Montana	1,144	2,099	3,303	6,658	9,437	46,570	69,211
Wyoming	864	1,008	2,111	2,493	7,459	24,677	38,612
Colorado	789	1,894	1,949	7,290	12,028	42,072	66,022
North Dakota	530	1,207	4,197	11,112	7,475	60,012	84,533
South Dakota	631	2,317	3,387	11,478	6,874	46,974	71,661
Nebraska	444	2,714	4,213	11,449	9,236	59,496	87,552
Minnesota	688	3,357	5,323	16,619	11,905	77,802	115,694
Iowa	650	3,145	4,957	13,506	16,398	65,124	103,780
Total	5,740	17,741	29,440	80,605	80,812	422,727	637,065

Source: Larson 1988.

Table 9.6—Number of cattle and milk cows in the United States, by region

Region	Cattle[1]	Dairy[2]
	Thousand	*head*
Northeast	339	2,795
North Central	5,755	4,579
Southeast	122	644
South Central	2,665	928
Rocky Mountain	1,893	534
Pacific Northwest	728	1,324
Total	11,502	10,804

Source: U.S. Department of Agriculture 1989b.

[1] Cattle and calves on feed as of January 1, 1988.
[2] Average number of milk cows during year (1986) excluding heifers not yet fresh.

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Source: U.S. Department of Agriculture 1989b.

[1] Cattle and calves on feed as of January 1, 1988.
[2] Average number of milk cows during year (1986) excluding heifers not yet fresh.

Table 9.7—Number of lots within the planning jurisdiction of selected cities in the Great Plains and the number of trees required to protect these sites adequately

	Total lots	Lots 1-5 acres	Lots 6-10 acres	Lots 11-20 acres	Trees required
Lincoln, NE[1]	4,354	2,090	1,629	634	670,516
Bismarck, ND[2]	2,856	2,495	304	57	448,392
Huron, SD[3]	299	222	38	39	46,943
Aberdeen, SD[3]	1,187	NA	NA	NA	186,359
Sioux Falls, SD[3]	2,289	NA	NA	NA	359,373

[1] Lincoln city/county planning office.
[2] Bismarck city planning office.
[3] South Dakota State Forester's office.

Table 9.8—Summary of minimum shelterbelt planting needs in the United States, by type of shelterbelt

Type of windbreak	Number of miles	Number of acres	Number of trees and shrubs required
Field shelterbelts			
For wind erosion control	1,400,000	3,400,000	920,000,000
For crop protection	486,254	1,200,000	320,900,000
Farmstead shelterbelts	26,700	284,486	55,100,000
Livestock shelterbelts	518	3,500	1,000,000
Living snow fence	6,370	19,000	6,370,000
Total	1,919,842	4,906,986	1,303,370,000

Table 9.9—Unweighted average heights in feet at 20 years for selected shelterbelt species across soil windbreak suitability groups and climate regions (adapted from technical guideline of the U.S. Department of Agriculture's Soil Conservation Service)

Species	Pacific Northwest	Rocky Mountains			North Central			Northeast	
	Washington	New Mexico	Utah/ Nevada	Colorado	North Dakota	Nebraska	Michigan	Ohio	Pennsylvania
Conifers									
Eastern white pine	NS[1]	NS	NS	NS	NS	27	26	30	32
Austrian pine	24	11	20	14	NS	20	22	22	24
Ponderosa pine	26	11	20	15	14	19	NS	NS	NS
Eastern redcedar	14	11	16	12	9	15	15	16	22
Blue spruce	14	10	22	16	16	20	19	20	20
Norway spruce	28	NS	22	NS	NS	26	26	27	30
Hardwoods									
Green ash	28	14	23	15	14	18	25	21	23
Bur oak	NS	12	NS	14	16	19	13	NS	NS
Pin oak	NS	NS	NS	NS	NS	24	15	34	35
Osage orange	NS	10	NS	13	NS	18	NS	20	23
Russianolive	17	13	17	14	11	15	NS	NS	NS
Golden willow	28	14	NS	20	22	28	33	33	33
Siberian elm/ Chinese elm	26	15	29	22	18	26	NS	20	28
Shrubs									
American plum	NS	7	8	7	6	7	NS	NS	NS
Lilac	9	5	7	6	5	6	9	8	9
Cotoneaster	4	4	7	5	7	6	9	6	8
Honeysuckle	8	6	NS	6	7	7	10	9	9
Siberian peashrub	9	7	8	7	6	7	8	8	9

[1]NS = species not suitable or recommended for this area.

Table 9.10—Unweighted average total tree volumes for common shelterbelt species[1]

Region/Species	Total tree volume, in cubic feet						
Northeast	Maine	Mass.	Ohio	New York			
Spruce	4.6	4.2	NA	3.8			
Eastern white pine	4.2	4.4	NA	NA			
Ash	4.1	4.9	4.0	4.1			
Elm	4.0	2.3	NA	NA			
North Central	No. Dakota	So. Dakota	Nebraska	Kansas	Wisconsin	Iowa	Indiana
Ponderosa pine	3.4	2.6	3.7	NA	NS	NS	NS
Eastern redcedar	NA	3.4	2.6	2.2	NA	2.9	5.0
Eastern white pine	NS	NS	NS	NS	4.3	NA	3.7
Spruce	NA	5.2	NA	NA	4.5	NA	NA
Ash	3.4	2.8	2.6	2.5	5.2	3.7	3.7
Elm	2.5	2.3	3.2	1.5	5.5	3.7	3.8
Hackberry	3.4	4.0	3.2	2.5	NA	3.2	NA
Cottonwood	3.1	3.5	3.4	3.2	6.6	5.2	4.5
South Central	Arkansas	Mississippi	Texas	Oklahoma	Tennessee		
Shortleaf or Loblolly pine	3.8	4.0	3.8	3.3	4.8		
Eastern redcedar	NA	NA	NA	3.3	3.8		
Cottonwood or Aspen	4.2	4.1	NA	NA	4.0		
Ash	NA	NA	NA	4.0	NA		
Rocky Mountain	Wyoming	Arizona	Montana	Idaho	New Mexico	Colorado	
Ponderosa pine	2.5	2.5	2.4	2.2	2.4	NA	
Spruce	3.9	2.9	3.6	5.4	NA	3.5	
Fir	4.0	3.1	NA	NA	3.2	2.4	
Lodgepole pine	NA	NA	5.2	NA	NA	5.3	
Cottonwood	NA	1.1	3.3	2.3	3.2	1.5	

Sources: Birdsey and Bertelson 1987, Collins 1989, Collins and Green 1988, Conner and Brown 1987, Considine and Frieswyk 1982, Dennis and Birch 1981, Dickson 1988, Donner and Hines 1988, Green and Conner 1989, Green et al. 1985, Hines and Vissage 1988, Jakes and Smith 1982, Lang and Bertelson 1987, May and Vissage 1989, Powell and Dickson 1984, Raile 1985 and 1986, Raile and Spencer 1984, Smith and Golitz 1988, Spencer and Jakes 1980, Van Hooser 1989, Van Hooser and Green 1985.

[1]Total tree volume includes stump/root system, merchantable bole to a 4-inch top, and crown.
NA = data not available.

NS = species not suitable or recommended for this location.

Table 9.11—Estimated biomass factors at 20 years for a typical conifer, hardwood, and shrub used in shelterbelt plantings

	Conifer	Hardwood	Shrub
Height (ft)[1]	20.1	21.9	7.3
Density (lb/ft^3)	27.1	34.1	[2]34.1
Single plant volume[3] (ft^3)	3.6	3.4	Unknown
Single plant weight (lb)	97.6	115.9	[4]4.7
Number of trees per row mile of shelterbelt	528	330	1,056
Within-row spacing (ft)	10	16	5
Volume per row mile (ft^3)	1,901	1,122	[2]147
Biomass per mile (lb)	51,533	38,247	[5]5,000

[1] See table 9.9.
[2] Shrubs are assumed to have the same wood density as hardwoods.
[3] See table 9.10.
[4] Calculated from the average aboveground biomass per row mile divided by the number of shrubs per mile.
[5] Aboveground biomass, stems, and branches.

Table 9.12—Summary of the potential for carbon storage and the carbon dioxide equivalent per mile of various types of shelterbelts

Shelterbelt	Cubic feet per mile	Average carbon storage	Average carbon dioxide equivalent
		Metric tons/mile	
Single-row conifer	1,901	14.7	53.6
Single-row hardwood	1,122	8.7	31.6
Single-row shrub	147	1.1	4.1
Farmstead shelterbelt[1]	5,071	39.2	142.9
Living snow fence[2]	5,703	44.1	160.7
"Typical" shelterbelt[3]	1,268	9.8	35.7

[1] Four rows: one shrub, two conifer, one hardwood.
[2] Three rows of conifers.
[3] Single row: 25 percent hardwoods, 50 percent conifers, 25 percent shrubs.

Table 9.13—Total potential carbon storage and carbon dioxide equivalent resulting from a minimum shelterbelt planting program

Type of shelterbelt	Number of miles	Total carbon storage	Carbon dioxide equivalent
		Million metric tons	
Wind erosion[1]	1,394,628	13.68	49.79
Crop protection[2]	486,254	7.15	26.06
Farmstead[3]	26,700	1.05	3.82
Living snow fence[4]	6,370	0.28	1.02
Total	1,913,952	22.16	80.69

[1] "Typical" shelterbelt design–table 9.12.
[2] Single-row shelterbelt design–table 9.12.
[3] Farmstead shelterbelt design–table 9.12; 177,741 farmsteads–table 9.4.
[4] Living snow fence design–table 9.12.

Table 9.14—Fuel use for the production of various nonirrigated crops in Nebraska

Crop	Fuel usage
	Gallons per acre
Corn	4.7–9.8
Soybeans	3.6–4.5
Winter wheat	2.7–9.7
Grain sorghum	5.2–10.1
Oats	3.0–4.3

Source: Jose, et al. 1989.

[1] Usage was based on diesel fuel at 60 cents/gallon.

Table 9.15—Equivalent acres[1] required to replace potential productivity lost as a result of 100 years of future wind erosion (adapted from U.S. Department of Agriculture 1989b)

State	Acres
Colorado	128,000
Idaho	66,000
Kansas	43,000
Minnesota	2,000
Montana	108,000
Nebraska	19,000
Nevada	31,000
New Mexico	10,000
Oklahoma	19,000
South Dakota	50,000
Texas	380,000
Washington	76,000
Wyoming	3,000
Total	935,000

[1] Equivalent acres are the number of additional acres needed after 100 years of wind erosion to produce the amount of crops currently produced.

Table 9.16—The effect of shelterbelt protection on consumption of home heating fuel and carbon dioxide emissions for a typical home[1] in 14 different cities

Region	Annual heat-season needs[2]	Natural gas consumption[3]	Fuel savings	Reduced CO_2 emissions[4]
	(BTU x 10^6)	*Thousand ft^3*		*Kg*
North Central				
Marquette, MI	212	283	42.4	1,399.2
Duluth, MN	203	274	40.6	1,339.8
Williston, ND	168	224	33.6	1,108.8
LaCrosse, WI	159	212	31.8	1,049.4
North Platte, NE	146	195	29.2	963.6
Topeka, KS	134	179	26.8	884.4
South Central				
Tulsa, OK	109	145	21.7	716.1
Abilene, TX	108	144	21.6	712.8
Rocky Mountains				
Cheyenne, WY	180	240	36.0	1188.0
Boise, ID	153	204	30.6	1009.8
Billings, MT	151	201	30.1	993.3
Grand Junction, CO	138	184	27.6	910.8
Pacific Northwest				
Seattle, WA	183	244	36.6	1,207.8
Spokane, WA	165	220	33.0	1,089.0

[1] All figures refer to a hypothetical dwelling with a basic heating requirement of 70,000 BTU per hour.

[2] Annual heating season needs = basic heating requirements per hour times 24 hours times (inside design temperature minus average outside temperature for the heating season) divided by (inside design temperature minus outside design temperature). A further explanation of these climate-related terms is available in Strock (1959).

[3] The heat value of natural gas depends on its local composition and furnace efficiency. Values of 882 BTU/ft^3 and 85 percent have been assumed.

[4] The amount of carbon dioxide released depends on the gas composition and combustion efficiency. A value of 33 kg/1,000 ft^3 from complete combustion has been assumed.

Table 9.17—Total energy savings and reduced carbon dioxide emissions that would result from a national farmstead-shelterbelt planting effort in targeted areas, over a 50-year period

	Region			
	North Central	Rocky Mountain	Pacific Northwest	Total
Number of new planted shelterbelts	90,286	20,379	36,076	146,741
Savings in natural gas (billion ft³)				
During years 1-20[1]	24.61	5.67	8.97	39.25
In years 21-50	92.27	21.28	33.63	147.18
Total, years 1-50	116.88	26.95	42.60	186.43
Reduced emissions of CO_2 (million metric tons)				
During years 1-20	27.66	6.52	9.19	43.37
In years 21-50	103.72	24.43	34.48	162.63
Total, years 1-50	131.38	30.95	43.67	206.00
Forestland required to sequester equivalent amounts of carbon[2]	1.84	0.43	0.61	2.88

[1] Establishment period is assumed to be 20 years. No benefits accrue during years 1-5. Benefits increase yearly beginning in year 6 and reach their maximum in year 20. Estimates of fuel use are based on the hypothetical home described in table 9.16.

[2] Approximate additional acres of commercial forestland—land capable of producing between 20 and 50 ft³ of wood volume per year—that would have to be planted in order to sequester the amounts of carbon that could be captured in shelterbelts described in this table.